METHODS AND SYSTEMS FOR COMPRESSING SONIC LOG DATA

DESCRIPTION

[Para 1] Field of the Invention

[Para 2] The invention relates generally to instruments for subsurface logging and exploration. More particularly, the invention relates to techniques for compressing log data for transmission via a selected telemetry format.

[Para 3] Background Art

[Para 4] The oil and gas industry uses various tools to probe the formation penetrated by a borehole in order to locate hydrocarbon reservoirs and to determine the types and quantities of hydrocarbons. Among these tools, sonic tools have been found to provide valuable information regarding formation properties. In sonic logging, a tool is typically lowered into a borehole, either after the well has been drilled or while the well is being drilled, and sonic energy is transmitted from a source into the borehole and surrounding formation. The sonic waves that travel in the formation are then detected with one or more receivers.

[Para 5] A typical sonic log can be recorded on a linear scale of slowness versus depth in the borehole, and is typically accompanied by an integrated-travel-time log in which each division indicates an increase of one microsecond of the total travel time period. Sonic logs are typically used as direct indications of subsurface properties or – in combination with other logs or other data of the subsurface properties – to determine the formation porosity and other parameters which cannot be measured directly.

[Para 6] Various analysis methods are available for deriving formation properties from the sonic log data. Among these, the slowness-time-coherence (STC) method is commonly used to process the monopole sonic signals for coherent arrivals, including the formation compressional, shear,

and borehole Stoneley waves. *See* U.S. Patent No. 4,594,691 issued to Kimball et al. and Kimball et al., Geophysics, Vol. 49 (1984), pp. 264-28.

[Para 7] For logging-while-drilling (LWD) sonic logging, it is desirable to send selected data uphole or wherever desired in real-time via mud pulse telemetry. Mud telemetry is a common method used in LWD operations to transmit log data to the surface. Mud telemetry makes use of the modulations of the pressure of a drilling fluid pumped through the drilling assembly to drill the wellbore. The fluid pressure modulation, however, can only transmit data at a rate of a few bits per second. A typical LWD sonic job requires too much bandwidth to transmit all the desired measured sonic data in real-time.

[Para 8] The limitations imposed on data transmission by a lack of adequate bandwidth are commonly encountered in various logging operations, not just sonic logging. Therefore, various methods for data compression have been developed to reduce the bandwidth requirement of conventional telemetry schemes. For example, U.S. Patent 5,381,092 issued to Freedman describes methods for compressing data produced from NMR well tools. The methods first subdivide a plurality of input signals into multiple groups, where the number of groups is much less than the number of input signals. The method then generates one value for each group. Thus a plurality of values corresponding to the plurality of groups represent the compressed input signals transmitted uphole.

[Para 9] U.S. Patent No. 5,031,155 issued to Hsu describes methods for compressing sonic data acquired in well logging. Samples of each digitized formation wave component are characterized as a vector. Eigenvectors based on the formation wave component vectors are obtained, and selected wave components are correlated to the eigenvectors to obtain scalar correlation factors. The eigenvectors and correlation factors together provide a compressed representation of the selected formation wave component.

[Para 10] U.S. Patent No. 6,691,036 issued to Blanch et al. describes methods for processing sonic waveforms. A method proposed in this application transforms an acoustic signal into the frequency domain to produce a frequency domain semblance and display the result in a graph with slowness

and frequency axes. Published U.S. Patent Application No. 2004/0145503 by Blanch et al. describe additional methods for processing sonic waveforms.

[Para 11] U.S. Patent No. 6,405,136 B1 issued to Li et al. describes compression methods for use in wellbore and formation characterization. The method includes performing a 2D transform on the data in the orientation domain and in a domain related to the recording time.

[Para 12] While these methods are useful in compressing log data and in reducing the bandwidth requirements of mud telemetry, a need remains for efficient techniques for downhole data compression.

[Para 13] SUMMARY OF INVENTION

[Para 14] One aspect of the invention relates to methods for compression of sonic log data. A method in accordance with one embodiment of the invention includes sorting peak components in the sonic log data; filtering the sorted peak components to remove high-frequency portions in the peak components; and decimating the filtered peak components according to a selected ratio to produce compressed data.

[Para 15] One aspect of the invention relates to methods for telemetry transmission of downhole sonic log data. A method in accordance with one embodiment of the invention includes sorting peak components in the sonic log data; compressing the sorted peak components to produce compressed data; packing the compressed data to produce data packets for telemetry transmission; and sending the data packets using telemetry.

[Para 16] One aspect of the invention relates to systems for compressing sonic log data. A system in accordance with one embodiment of the invention includes a processor and a memory, wherein the memory stores a program having instructions for: sorting peak components in the sonic log data; filtering the sorted peak components to remove high-frequency portions in the peak components; and decimating the filtered peak components according to a selected ratio to produce compressed data

[Para 17] BRIEF DESCRIPTION OF DRAWINGS

[Para 18] FIG. 1 shows a prior art logging-while-drilling system having a tool disposed in a borehole.

[Para 19] FIGs. 2A-2C show sonic log data derived coherence peak attributes as calculated by a prior art slowness-time-coherence method.

[Para 20] FIG. 3 shows a plot of maximum spatial frequency as a function of drilling speed.

[Para 21] FIG. 4 shows a method for data compression in accordance with one embodiment of the invention.

[Para 22] FIG. 5 shows a method for data decompression in accordance with one embodiment of the invention.

[Para 23] FIGs. 6A-6C show peak attributes after sorting of peak components in accordance with one method of the invention.

[Para 24] FIGs. 7A-7D show comparisons in the time domain between the original DTPK peak attributes and the compressed-decompressed DTPK peak attributes in accordance with one embodiment of the invention.

[Para 25] FIGs. 8A-8D show comparisons in the depth domain between the original DTPK peak attributes and the compressed-decompressed DTPK peak attributes in accordance with one embodiment of the invention.

[Para 26] FIGs. 9A-9D show comparisons in the time domain between the original COPK peak attributes and the compressed-decompressed COPK peak attributes in accordance with one embodiment of the invention.

[Para 27] FIGs. 10A-10D show comparisons in the depth domain between the original COPK peak attributes and the compressed-decompressed COPK peak attributes in accordance with one embodiment of the invention.

[Para 28] FIGs. 11A-11D show comparisons in the time domain between the original TTPK peak attributes and the compressed-decompressed TTPK peak attributes in accordance with one embodiment of the invention.

[Para 29] FIGs. 12A-12D show comparisons in the depth domain between the original TTPK peak attributes and the compressed-decompressed TTPK peak attributes in accordance with one embodiment of the invention.

[Para 30] FIGs. 13 show original STPP as compared with peak attributes before and after compression and decompression in accordance with one embodiment of the invention.

[Para 31] DETAILED DESCRIPTION

[Para 32] Embodiments of the invention relate to techniques for compressing downhole data (e.g., attributes of sonic coherence peaks). These compression schemes may be used to reduce telemetry bandwidth requirements for sending data uphole (e.g., in LWD operations) or to reduce the memory required for storing data for later retrieval (e.g., in logging-while-tripping operations). Embodiments of the invention may be implemented in existing downhole tools (e.g., sonic instruments or other logging tools) or incorporated with future instruments to transmit real-time information where desired. Sonic tools are available for wireline, while-tripping, long-term monitoring, and LWD operations as known in the art. Sonic tools for LWD logging, for example, are described in U.S. Patent No. 5,852,587 issued to Kostek et al. When used for sonic implementations, the disclosed techniques are applicable to acoustic wave data produced in all modes of excitation (e.g., monopole, dipole, quadrupole, octupole).

[Para 33] FIG. 1 shows a general illustration of a drilling rig and a drill string with a downhole logging tool in a borehole. The rotary drilling rig shown comprises a mast 1 rising above ground 2 and is fitted with a lifting gear 3. A drill string 4 formed of drill pipes screwed one to another is suspended from the lifting gear 3. The drill string 4 has at its lower end a drill bit 5 for the drilling well 6. Lifting gear 3 consists of crown block 7, the axis of which is fixed to the top of mast 1, vertically traveling block 8, to which is attached hook 9, cable 10 passing round blocks 7 and 8 and forming, from crown block 7, on one hand dead line 10a anchored to fixed point 11 and on the other active line 10b which winds round the drum of winch 12.

[Para 34] Drill string 4 is suspended from hook 9 by means of swivel 13, which is linked by hose 14 to mud pump 15. Pump 15 permits the injection of drilling mud into well 6, via the hollow pipes of drill string 4. The drilling mud may be drawn from mud pit 16, which may be fed with surplus mud from well

6. The drill string 4 may be elevated by turning lifting gear 3 with winch 12. Drill pipe raising and lowering operations require drill string 4 to be temporarily unhooked from lifting gear 3; the former is then supported by blocking it with wedges 17 in conical recess 18 in rotating table 19 that is mounted on platform 20, through which the drill string passes. The lower portion of the drill string 4 may include one or more tools, as shown at 30, for investigating downhole drilling conditions or for investigating the properties of the geological formations. Tool 30 shown is an acoustic logging tool having at least one transmitter and a plurality of receivers spaced therefrom.

[Para 35] Variations in height h of traveling block 8 during drill string raising operations are measured by means of sensor 23 which may be an angle of rotation sensor coupled to the faster pulley of crown block 7. Weight applied to hook 9 of traveling block 8 may also be measured by means of strain gauge 24 inserted into dead line 10a of cable 10 to measure its tension. Sensors 23 and 24 are connected by lines 25 and 26 to processing unit 27 which processes the measurement signals and which incorporates a clock. Recorder 28 is connected to processing unit 27, which is preferably a computer. In addition, the downhole sonic tool 30 may include a processing unit 30a. The downhole processing unit 30a and/or the surface processing unit 27 may be used to perform the data compression and decompression in accordance with embodiments of the invention.

[Para 36] Sonic data acquired in this manner is typically displayed on a chart, or log, of waveform amplitude over time versus depth. As noted above, the slowness-time-coherence (STC) method is among the most commonly used in sonic data analysis. This method systematically computes the coherence (C) of the signals in time windows which start at a given time (T) and have a given window moveout slowness (S) across the array. The 2D plane C(S,T) is called the slowness-time plane (STP). All the coherent arrivals in the waveform will show up in the STP as prominent coherent peaks. The three attributes of a coherent peak are the peak coherent value (COPK) and the peak location in the slowness-time plane (DTPK and TTPK). The attributes of these prominent coherent peaks represent the condensed information extracted from the

recorded waveforms. The attributes show the coherence, arrival time, and propagation slowness of all prominent wave components detected from the waveforms.

[Para 37] The peak attributes can be used uphole as input to a selection process called "labeling" to determine the compressional (P), shear (S), and Stoneley (St) slowness logs. The peak attributes can also be used to generate a synthetic slowness-time-plane projection (STTP) for real-time quality control purpose. In any given zone, if the compressional DT log matches to a group of peaks with high coherence, steady DT value, and consistent arrival time, the likelihood of accurate measurement is high. In order to accommodate the mud telemetry bandwidth, the downhole software onboard a sonic tool can select only a few peaks (e.g., 4 peaks) to transmit uphole. First, the software would search for coherent peaks above a given threshold value (usually 0.4) in the STP. There may be a large number of peaks that have coherence above this threshold. The software would then sort the peaks according to descending order of coherence and retains only the top peaks (e.g. top 4).

[Para 38] The bandwidth required to send the 4 highest coherent peaks uphole is significant. The following table shows the number of bits required to represent typical coherence attributes of a single peak.

Peak attributes	COPK	DTPK	TTPK
Bit assignment	3	7	4

[Para 39] It requires 14 bits to represent one peak and 56 bits for 4 peaks at any given data frame. Assuming the data frame rate is 10 second per frame, the bit rate requirement for sending the attributes of the 4 peaks uphole is 5.6 bits/sec, which is a restrictive value for most field jobs.

[Para 40] The disclosed methods can compress data with little loss. Under normal circumstance, a compression factor of 4 can be achieved without significant loss of information. A reduction (data compression) by a factor of 4 will make the bit rate requirement for sending data via mud telemetry possible

for many applications, including sonic logs. Using sonic logs as an example, with a factor of 4 compression, the peak attributes of 4 peaks can be transmitted at 1.4 bits/sec for 10-second frame rates.

[Para 41] FIGs. 2A-2C show peak attributes of DTPK, COPK, and TTPK, respectively, as functions of time from a typical sonic job. These peaks are typically sorted by coherences, which are not associated with any major wave component. For example, the P component may have the highest coherence in a given data frame, while the St component may have the highest coherence in the next frame. As a result, the peak attributes as functions of time, as shown in FIGs. 2A-2C, appear to be random distributions of noises. This is especially true for DTPK (FIG. 2A) and TTPK (FIG. 2C), which include the most important information in a sonic log. Thus, the coherence sorted peak attributes may not be the most desirable method for presenting the sonic data.

[Para 42] It is apparent from FIGs. 2A-2C that the peak attributes are full of high frequency components. From the signal processing point of view, high frequency signals require wide bandwidth to represent them adequately, and, therefore, it would be difficult to compress high frequency signals. High frequency representation of the peak attributes may not be necessary.

[Para 43] First, sonic tools are designed to measure slowness of major wave components regardless of coherence, and the high frequency components in the coherence sorted peak attribute data typically are not related to the major wave components. Thus, the real information of interest do not require high frequency representations. Furthermore, the receiver arrays of conventional sonic tools typically span a few feet (e.g., a 2-ft [0.61 m] aperture) along the longitudinal axis of the tool, and the measured slowness of the wave components is typically averaged over the receiver aperture. Essentially, the 2-ft [0.61 m] aperture acts like a low-pass filter, removing high-frequency components. Therefore, the measured P, S, and St slownesses should be slowly varying functions in both the time domain and the depth domain.

[Para 44] In addition, drilling speeds can also affect maximum spatial frequencies (Nyquist frequency) measurable in sonic logs. FIG. 3 shows a plot of the Nyquist frequency as a function of drilling speeds (i.e., the rate of

penetration (ROP) in a drilling operation). The data shown in FIG. 3 are for LWD loggings with 10-second data frame rates. Curve 1 shows the Nyquist frequency (maximum spatial frequency, cycle/ft) for a drilling process with an ROP ranging from 20 - 200 ft/hr [6.1-61m/hr]. Curve 1 clearly shows that the maximum achievable spatial frequency decreases substantially as the ROP increases. When the measurements are averaged over a 2-ft [0.61 m] aperture, whose -3 dB point is shown as Curve 3, the maximum spatial frequencies achievable is significantly reduced. A comparison between Curve 1 and Curve 3 clearly shows that within the common ROP range of 20-200 ft/hr [6.1-61m/hr], the maximum spatial frequency allowed by the drilling rate is substantially higher than the -3dB point of the 2-ft [0.61 m] array aperture, especially in the slower ROP range. In other words, the common practice of averaging over the 2-ft [0.61 m] aperture significantly compromises the information contents of the logs.

[Para 45] While averaging over the 2-ft [0.61 m] aperture may lose a portion of the information content, it is often impractical to record and transmit the full bandwidth of raw data. The important information content of the log is typically included in the lower portion (e.g. lower 25%) of the spatial frequency spectrum. Therefore, a compression scheme (e.g., a band limited data compression scheme), which keeps only the lower portion (e.g. 25%) of the spatial frequency, should have minimal loss of information. Curve 2 represents the lower 25% of the spatial frequency. Thus, by keeping only the lower portion of the spatial frequency, the data is effectively compressed by a factor of four, without a significant loss of information.

[Para 46] The above observations together suggest that sonic log data can be efficiently compressed without loss of much information by keeping mostly the low frequency components. In addition, it may be advantageous to sort the peak attributes according to the peak components, rather than the magnitudes of the coherences. Based on these considerations, embodiments of the invention present techniques for effective data compression that can be implemented in a downhole tool to reduce the telemetry bandwidth

requirements or to reduce the memory requirement for storing log data for later retrieval.

[Para 47] Methods of the invention for data compression are based on resorting of the peak attributes according to wave components, rather than according to coherences. FIG. 4 shows a block diagram of a compression method 40 in accordance with one embodiment of the invention. The peak attributes of original peak matrix 41 are first sorted, according to the wave components, into P, S, St, and other waves (step 42). After these peak attributes are sorted, a low-pass filter may be applied to each peak component to filter out the high frequency bands (e.g., to cut off the top 75% frequency bands) (step 43). The low-pass filter is applied across the time frame. The low pass filtered peak attributes are then decimated to compact the data (step 44). A decimation ratio for use in a method of the invention preferably matches the total frequency band to low-pass filter pass band ratio. For example, if a low pass filter is used to cut off the top 75% frequency bands, then a 4:1 ratio is preferred for the decimation. Steps 43 and 44 effectively remove the higher frequency portion of the peak attributes. One of ordinary skill in the art will appreciate that these two steps are for illustration only, and other methods may be used to achieve the same results. For example, the peak attributes in each sorted peak component may be sorted in the frequency domain and the high frequency portions discarded.

[Para 48] Once the peak attributes have been filtered and decimated, the remaining portion is ready for transmission uphole. The data that are to be transmitted may be encoded in a suitable bit-encoding format for mud telemetry (or other telemetry) (step 45). For example, one may assign 3 bits to encode the magnitudes of peak coherences, 7 bits to DT, and 4 bits to TT. Next, the encoded bits are packed in frames (data packets) for telemetry transmission (step 46) and the data packets are sent where desired (step 47).

[Para 49] Once the compressed data are sent to the surface, they can be decompressed to "reconstruct" the peak attributes in a process that in most part is a reverse of the compression process used to compress the data. FIG. 5 shows a method of decompression 50 in accordance with one embodiment of

the invention. First, the encoded bits from the telemetry container (e.g., the mud pulse packed data 51) are unpacked to restore the decimated peak matrix structure (step 52). Then, the bits are decoded to recover the decimated peak attributes (step 53). The decimated peak attributes are then interpolated to "reconstruct" the peak attributes (step 54). The interpolation may be accomplished with any method known in the art, for example by harmonic interpolation. The interpolation ratio preferably matches the ratio used to compress the data (see step 44 in FIG. 4). The last few data points from the interpolation may have artifacts. These artifacts may be minimized (or removed) by overlapping the last few points with the next data set (step 55). Once these peak attributes are "reconstructed", they may be used to synthesize STPP (step 56) or to label the sonic logs DTc, DTs, DTst (step 57).

[Para 50] Note that the specific methods described in FIG. 4 and FIG. 5 are for illustration only. One of ordinary skill in the art will appreciate that variations of these processes are possible without departing from the scope of the invention. For example, the specific reference of the lower 25% of the spatial frequency and the 4-to-1 decimation described are values that work well for conventional LWD sonic tools. However, other percentages and/or decimation ratios may also be used to implement the disclosed schemes. That is, techniques of the invention are not limited to any specific frequency band and/or decimation ratio.

[Para 51] FIG. 4 and FIG. 5 outline the general schemes for data compression and decompression. Details of the steps involved are described below.

[Para 52] Peak sorting according to wave components: P, S, St, O (other)

[Para 53] One of ordinary skill in the art will appreciate that there are many ways to sort the peaks according to the wave components. The following describes a simple procedure that has been found to work quite robustly on field data.

[Para 54] The wave component peak selection process may be based on factors that reflect peak characteristics. For example, the following factors may be used for peak selection: (a) Coherence, (b) Slowness consistent with arrival time for the given transmitter-to-receiver spacing (TR), (c) Early arrival

(for P component only), and (d) Late arrival (for St component only). Each of these factors may be associated with a weighting coefficient to yield a cost function for that factor. The total cost function may then be described as the sum of the cost functions for the individual factors.

[Para 55] In sonic logging, the first signal to arrive at a receiver is generally the compressional wave (P-wave), which travels from the transmitter to the receiver through the formation adjacent the borehole. The second signal arrival is generally the shear wave (S-wave). Then, the Stoneley wave (St) comes next. Because the P-wave comes earlier, it would be easier to sort out the P components first. Thus, in accordance with one embodiment of the invention, the lowest cost peak for P component is determined first. Then, the lowest cost peak for the S component is selected from the remaining peaks. The lowest cost peak for the St component is determined next from the remaining peaks after P and S peak selection. Finally, the remaining peaks after the P, S, and St peak selection are labeled “O” for “others.”

[Para 56] In addition, other rules may be used in conjunction with the selection rules outlined above. For example, the P peaks may be preferentially selected from those having slowness within a practical limit, such as the compressional label limits that are part of the downhole tool configuration parameters. Similarly, the S peaks may be preferentially selected from those having a slowness typically expected of a shear wave. The St peaks may also be preferentially selected from those having slowness higher than the mud slowness.

[Para 57] Sometimes, the P component peak may be missing from the STC processing for a few frames. This situation may arise from a faulty peak search algorithm or noise problems. When the P component is missing, the sorting algorithm may incorrectly assign the S peak as the P peak over these few frames. If this happens, the resulting P peak slowness may have a spike (anomaly) over these few frames. To improve the situation, a de-spiking process may be included in P peak sorting to detect any spike. A spike may be defined as an anomaly having a width of a few frames. Such a spike can be detected, for example, by using a suitable filter. If a P spike is detected, the P

peak attributes may be reassigned to a median value. After de-spiking, the attributes of the S, St, and O peaks may be reassigned from the original peak attributes using the minimum cost and slowness range rules.

[Para 58] In accordance with embodiments of the invention, the peak sorting algorithm (and peak de-spiking algorithm) may be implemented in any suitable software, including commercially available packages such as Matlab™ from MathWorks (Natick, MA). The peak sorting algorithm may include a quality indicator to indicate the quality of the wave-component peak sorting. A quality indicator may be based on the cost function described above or any other suitable function. One of ordinary skill in the art will understand how to implement appropriate algorithm codes in accord with the techniques disclosed herein.

[Para 59] Band-limited compression/decompression for the wave component sorted peak attributes

[Para 60] The wave-component-sorted peak attributes are slowly varying functions with information content primarily in the lower 25% of the frequency band. Therefore, in accordance with embodiments of the invention, a standard band limited compression algorithm may be selected to compress the sorted peak attributes. For example, a time domain version of the band-limited compression may be used. However, one of ordinary skill in the art will appreciate that other approaches may be used without departing from the scope of the invention.

[Para 61] In accordance with one embodiment of the invention, a time domain based band-limited compression algorithm is used. The algorithm consists of low-pass filtering, followed by a four-to-one (or any other suitable ratio) decimation (see e.g., FIG. 4). The corresponding decompression step then uses a one-to-four (or other ratio corresponding to the compression ratio) harmonic interpolation to "reconstruct" the peak attributes. Harmonic interpolation assumes cyclic data and, therefore, artifacts (end point truncation effect) may appear at the end of data set. Several approaches may be used to eliminate this truncation artifact. For example, the last 4 points (if one-to-four decompression is used) of the interpolated data may be overwritten by the

first 4 points of the next interpolated record, and the next record may be generated from an overlapped input that includes a repeated last data point of the last record.

[Para 62] In accordance with some embodiments of the invention, a quality indicator may be derived to provide indication of the quality of the compression. For example, a quality indicator may be based on the ratio of the spectral energy in the lower 25% of the frequency band to that in the upper 75% of the frequency band to indicate the quality of the compression.

[Para 63] The following examples illustrate the utility of methods in accordance with embodiments of the invention as applied to actual sonic log data.

[Para 64] Results from Sonic Data

[Para 65] FIGs. 6A-6C show the wave-component-sorted peak attributes of sonic data from a Texas well. The wave-component-sorted peak attributes shown in FIGs 6A-6C correspond to the same data shown as coherence-sorted peak attributes in FIG. 2. Note that the slowness (CTPK; FIG. 6A) and travel time (TTPK; FIG. 6C) of the P peak are very slow varying low frequency signals. There are a few places where the P peak attributes exhibit square-wave types of changes. These changes are typically due to rapid movements of the drill pipe during pipe change operations.

[Para 66] Similarly, as shown in FIGs. 6A-6C, the S and St peak attributes are also slowly varying signals over the zones where the S and St components exist. The O peak attributes generally retain the higher frequency form. This is expected because the O peaks are generally due to noise. In the compression process, the high frequency information of the attributes of the O peaks is lost and, therefore, the decompressed (reconstructed) attributes are smoother. In some embodiments of the invention, the O peak attributes may be skipped in telemetry transmission so as to reduce the telemetry bandwidth requirement if desired.

[Para 67] FIGs. 7A-7D respectively show comparisons between the original wave-component-sorted DTPK attributes and the compressed/decompressed

DTPK for the P, S, St, and O peaks. The data in FIGs. 7A-7D are still in time domain. After gating to the depth domain, the same comparisons are shown in FIGs. 8A-8D. The matches between the original and the compressed/decompressed data for the P peak are excellent (see FIG. 7A; FIG. 8A). These comparisons show that there is practically no loss in information due to the compression and decompression. For the S peaks (FIG. 7B; FIG. 8B) and St peaks (FIG. 7C; FIG. 8c), the matches are also very good over the zones where these wave components exist.

[Para 68] Similarly, FIG. 9 and FIG. 10 respectively show comparisons between the original wave-component-sorted COPK attributes and the compressed/decompressed COPK attributes in the time and depth domains. In each Figure, panels (A) - (D) respectively correspond to the P, S, St, and O peaks. It is apparent that good matches are observed between the original wave-component-sorted and the compress/decompressed attributes, suggesting very little loss of information with the disclosed compression and decompression techniques.

[Para 69] FIG. 11 and FIG. 12 respectively show a comparison between the original wave-component-sorted TTPK attributes and the compressed/decompressed TTPK attributes in the time and depth domain. In each Figure, panels (A) - (D) respectively correspond to the P, S, St, and O peaks. Again, these comparisons show that very little information is lost with the compression and decompression techniques of the invention.

[Para 70] FIGs. 13A-13C show comparisons among the high-resolution recorded mode STPP plot (FIG. 13A), STPP synthesized from the original peak attributes (FIG. 13B), and STPP synthesized from the compressed/decompressed peak attributes (FIG. 13C). In this particular example, only 2 bits were assigned to represent the COPK attributes. Also plotted on the STPP are the wave-component-sorted DTPK for the P and S peaks. It is apparent that the STPP from the compressed-decompressed data matches well with that from the original peak attributes over the zones where the wave components exist. Over some small gaps of missing wave components, the compressed-decompressed data actually produce smoothed

curves bridging over the gaps. Thus, sonic data compressed and decompressed by an embodiment of the invention produces more realistic images by "interpolating" the missing peaks.

[Para 71] Some embodiments of the invention relate to systems for performing methods of the invention. A system of the invention may be implemented on the processor in the downhole tool or on a surface processor, which may be a general purpose computer. FIG. 14 shows a schematic of a prior art general purpose computer that may be used with embodiments of the invention. As shown, the computer includes a display 110, a main unit 100, and input devices such as a keyboard 106 and a mouse 108. The main unit 100 may include a central processor 102 and a memory 104. The memory 104 may store programs having instructions for performing methods of the invention. Alternatively, other internal or removable storage may be used, such as a floppy disk, a CD ROM or other optical disk, a magnetic tape, a read-only memory chip (ROM), and other forms of the kind known in the art or subsequently developed. The program of instructions may be in object code or source codes. The precise forms of the program storage device and of the encoding of instructions are immaterial here.

[Para 72] Advantages of embodiments of the invention include methods for effective data compression without significant loss of information. The disclosed compression techniques are based on signal characteristics to preserve the information content of the original signals. The compression methods in accord with embodiments of the invention may enable real-time transmission of downhole data that would otherwise be impossible to transmit using mud telemetry. Embodiments of the invention may also be used to compress data to minimize telemetry bandwidth requirements. Embodiments may also be used to compress data downhole for storage, in order to save memory. The saved data may then be retrieved for later processing (e.g. when the instrument is tripped out of the well).

[Para 73] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do

not depart from the scope of the invention as disclosed herein. For example, while mud telemetry is described as a transmission means herein, those skilled in the art will appreciate that other telemetry means may be used to implement the disclosed techniques. For the purposes of this specification it will be clearly understood that the word "comprising" means "including but not limited to", and that the word "comprises" has a corresponding meaning.

CLAIMS